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First Named Applicant: Lotspiech	Art Unit: 2137
Serial No.: 09/771,239	Examiner: Davis
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For: METHOD FOR TRACING TRAITOR RECEIVERS IN A BROADCAST ENCRYPTION SYSTEM	September 20, 2004 750 B STREET, Suite 3120 San Diego, CA 92101

DECLARATION UNDER RULE 131

Commissioner of Patents and Trademarks
Washington, DC 20231

Dear Sir:

We, the below-named inventors of the above-captioned application, declare as follows:

As evidenced by the enclosed relevant pages from the IBM Invention Disclosure form dated as being created on September 14, 2000 and modified on December 7, 2000 (cover page of enclosed disclosure), we conceived of the present invention at least prior to January 1, 2001. Specifically, using the limitations of Claim 4 as an example and referring to the enclosed document, the inventors conceived of a method for identifying or disabling at least one traitor receiver with an associated unique, compromised decryption key in a broadcast encryption system (first content page of disclosure, first paragraph, discussing broadcast to users that have their own keys, which may "leak" if a device is a traitor); receiving a set of subsets derived from a tree defining leaves, each leaf representing a respective receiver (second content page, discussing "complete subtree" and "subtree difference" methods; bottom of third page continuing to top of fourth page, discussing partitioning subsets only if it contains a traitor and continuing to partition

until a subset contains only a single traitor, which can then be revoked); identifying at least one traitor subset from the set of subsets as containing at least one leaf representing a traitor receiver, (see above), using the traitor subset, identifying or disabling the traitor receiver (fourth page, fist bullet); and determining whether the traitor subset represents at least two traitor receivers, and if so, dividing the traitor subset into two child sets, fourth page, second bullet. Also, the specific method may include encoding plural subsets of the set of subsets with a false key, bottom of fifth page continuing to sixth page. The disclosure also teaches several additional features of one or more dependent claims as shown in the various pages enclosed herewith.

We declare that the inventors and assignee were diligent in reducing the invention to practice at least from a time prior to January 1, 2001 at least to the present filing date. Specifically, we declare that the enclosed invention disclosure prior to January 1, 2001 to IBM Intellectual Property Department, which then diligently processed the application for disclosure to outside counsel in December 2000. A first draft application was prepared for inventor review on January 5, 2001, which was then diligently reviewed for filing on January 26, 2001 within the usual course of IBM business in filing patent applications.

We hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United State Code and that such willful, false statements may jeopardize the validity of the application or any patent issued thereon.

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1053-122.AFF

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Disclosure ARC8-2000-0378

Prepared for and/or by an IBM Attorney - IBM Confidential

Created By: Dalit Naor **Created On:** 09/14/2000 01:36:11 PM
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Required fields are marked with the asterisk (*) and must be filled in to complete the form .

***Title of disclosure (in English)**

A Subset-based Traitors Tracing Mechanism

Summary

Status	Under Evaluation
Processing Location	ARC
Functional Area	DPEB - Image & Multimedia Systems - (Robin Williams)
Attorney/Patent Professional	Marc D McSwain/Almaden/IBM
IDT Team	Robin Williams/Almaden/IBM; Hui-I Hsiao/Almaden/IBM; Bruce Lindsay/Almaden/IBM; C Mohan/Almaden/IBM; Spencer Ng/Almaden/IBM; Thomas Zimmerman/Almaden/IBM; Myron Flickner/Almaden/IBM; Anant Jhingran/Almaden/IBM; Marc D McSwain/Almaden/IBM
Submitted Date	11/16/2000 04:35:56 PM
Owning Division	RES
Lab	
Technology Code	
PVT Score	No PVT score has been calculated.To calculate a PVT score, press the 'Calculate' button.

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Response Due to IP&L : 12/21/2000

***Main Idea**

1. Describe your invention, stating the problem solved (if appropriate), and indicating the advantages of using the invention.

Good
HG

This invention deals with prevention of piracy in the context of digital content distribution. Consider an encryption scheme whereby a Center broadcasts a message to a group of users so that only a subset of the users should be able to obtain the content of the message. Such schemes are naturally used for distribution of copyright protected content (such as music and movies) or for subscription-based systems (e.g. pay TV and Web Casting). A common problem with such schemes is that keys of certain users may leak and further be used by pirate decoders, software clones and other illegal means, thereby violating ownership rights of the data.

The invention provides a mechanism to combat the leakage of keys and their subsequent use by illegal decryption-boxes. Suppose that a pirate decryption-box contains the keys associated with at most t users $u_1, \ldots, u_t$ known as the "**traitors**". The goal of a tracing algorithm is to either

1. find the identities of those that contributed their keys to an illicit decryption box , or
2. render the box useless by finding a "pattern" that does not allow decryption using the box, but still allows broadcasting to the legitimate users.

When combined with an encryption scheme that is capable of revoking illegal users from future communications it yields a **trace-and-revoke** mechanism, which is a powerful tool to combat piracy. A tracing algorithm is evaluated based on (i) the number of illegal keys it is able to trace (ii) the level of performance downgrade it imposes on the encryption scheme (iii) the number of queries needed to trace the box.

The suggested scheme is a **black-box** tracing, i.e. one that does not take the decoder apart but by providing it with an encrypted message and observing its output (the decrypted message) tries to figure out who leaked the keys. It assumes that messages are encrypted using a **Subset-Cover** encryption scheme which satisfies the **bifurcation** property. The precise nature of such encryption schemes is defined below; two preferred embodiments for subset-cover revocation schemes having the bifurcation property are the Complete-Subtree method and the Subset-Difference method which are the subjects of Disclosure ~~#~~ ...

mandatory

Advantages of using this invention are:

1. In order to ~~trace t illegal users~~, it requires a message that consists of *t log N* keys where *N* is the total number of users in the entire system. A further improvement requires a message length of only *5t*

inventions. A Subset-Cover encryption scheme works as follows (as it covers all privileged users by smaller subsets).

- Each user u is initially assigned some secret information denote by I_u (typically, these are sets of keys).
- The scheme defines a collection of subsets of users $S_1, \ldots, S_w$ and their corresponding keys $K_1, \ldots, K_w$ so that for any $1 \leq i \leq w$ a user u can compute K_i from I_u if and only if it belongs to the subset S_i.
- Given M and P, The set P is partitioned into disjoint subsets $S = S\_i_1, S\_i_2, \ldots, S\_i_m$ so that every privileged user is in exactly one subset. M is then encrypted with the keys corresponding to these subsets:

$$< E_{K_{i1}}(K), E_{K_{i2}}(K), \ldots, E_{K_{im}}(K), F_K(M) >$$

This allows the users in P, and only them, to obtain M.

Bifurcation property

Our tracing mechanism requires that the Subset Cover algorithm satisfy the *bifurcation property*. The bifurcation property implies that for any subset S_i it is possible to partition S_i into two (or any constant) roughly equal sets and encrypt M using the two new sets instead of using S_i, i.e. there exist sets S_i_1 and S_i_2 such that

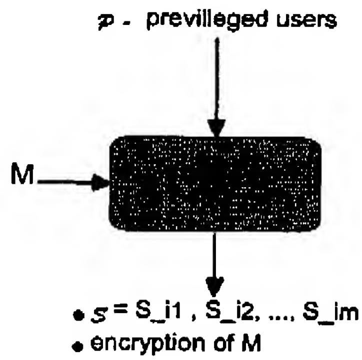
1. $S\_i = S\_i_1 \cup S\_i_2$
2. the size of S_i_1 is roughly the same as of S_i_2

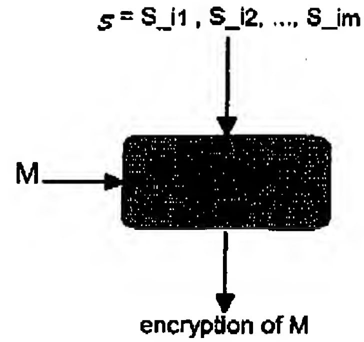
For a Subset Cover scheme, let the **bifurcation value** be the relative size of the largest subset in such a split.

The two preferred embodiments for a Subset-Cover revocation scheme, the Complete Subtree and the Subtree Difference methods, satisfy the bifurcation property. In the case of the Complete Subtree Method. the bifurcation value is 1/2 and for the Subtree Difference Method, the bifurcation value is 2/3.

Moreover, the Subtree Difference Method has an additional useful property: given any collection of r subsets $S\_i_1, \ldots, S\_i_r$, the method can cover all users that are *not* in $S\_i_1, \ldots, S\_i_r$ by at most 3r subsets.

In the discussion that follows the encryption scheme is viewed as a "box" that is capable of encrypting M when provided with either a specific partition S of all privileged users, or with the actual set P of privileged set of users. In the later, the partition that was used is also output. See diagram below.





The Tracing Algorithm

Let N be the total number of users in the system. Suppose that a pirate decryption-box contains the keys associated with at most t users $u_1, \ldots, u_t$ known as the "**traitors**". The invention is a subsets-based **tracing algorithm**. It devises a sequence of queries that are given to the decoder whose result is either

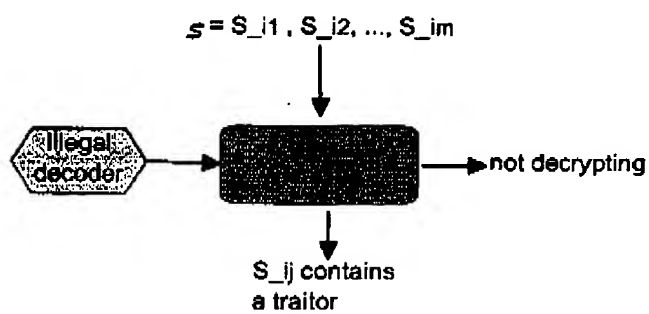
- a subset of users consisting of the traitors, or
- a partition of users into subsets that renders the box useless, i.e. given a message that is encrypted with the given partition, the box decrypts the message with probability smaller than the threshold q while all good users can still decrypt.

Naturally, the tracing algorithm is based on constructing a useful sequence of partitions which will finally allow the detection of a traitor's identity.

An important procedure in our tracing mechanism is one that given a partition $S = S\_i_1, S\_i_2, \ldots, S\_i_m$ and an illegal box outputs one of two possible outputs: either

1. The box cannot decrypt when the encryption is done with partition S, or
2. Finds a subset S_i_j such that S_i_j contains a traitor.

Such a procedure is called **subset tracing**.

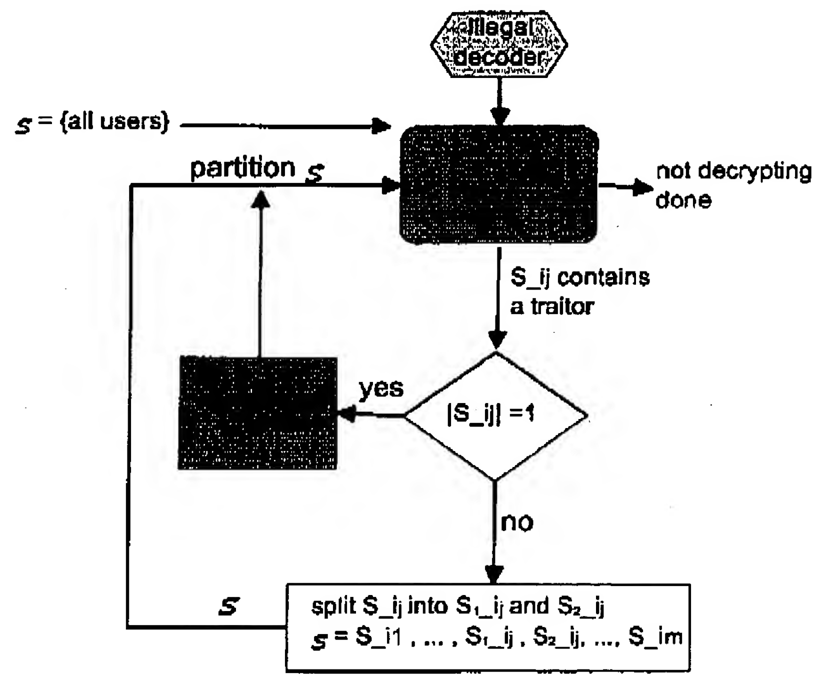


We explain our subset tracing procedure below. For now, let us assume that one exists, and we will now describe the general **tracing algorithm**, that uses the subset tracing procedure as a subroutine. The general algorithm maintains a partition $S = S\_i_1, S\_i_2, \ldots, S\_i_m$. At each phase one of the subsets is partitioned, and the goal is to partition a subset only if it contains a traitor. The initial partition is S = {all users}. A phase proceeds as follows:

At the beginning of the phase run the subset-tracing procedure with partition $S = S\_i_1, S\_i_2, \ldots, S\_i_m$.

- If the procedure outputs that the box cannot decrypt with S then we are done, in the sense that we have found a way to disable the box without hurting any legitimate user.
- Otherwise,
  Let S_i_j be the set output by the subset-tracing procedure, namely S_i_j contains the a traitor.
  - If S_i_j contains only one possible candidate - it must be a traitor. Permanently revoke this user from the set of privileged users.
  - Otherwise, split S_i_j into two roughly equal subset and continue with the new partitioning. The existence of such a split is assured by the bifurcation property.

The number of iterations of the above can be at most $t \log_a N$, where a is the inverse of the bifurcation value.



The Subset Tracing Procedure:

The Subset Tracing procedure first tests whether the box decodes a message that is legally encoded with the partition $S = S\_i_1, S\_i_2, \ldots, S\_i_m$ with sufficient probability, say $p > 0.5$. By "legally encoded" we mean a normal message that would look exactly like normal operation. If the box does not decode, then it concludes (and outputs) that the box can not decrypt with S . Otherwise, it needs to find a subset S_i_j that contains a traitor.

Such a subset is found as follows. Let p_j be the probability that the box decodes the ciphertext

$$< E_{K_{i1}}(R_K), E_{K_{i2}}(R_K), \ldots, E_{K_{ij}}(R_K), E_{K_{ij+1}}(K), \ldots, E_{K_{im}}(K), F_K(M) >$$

where R_K is a random string of the same length as the key K; i.e., it is a false key. That is, p_j is the

probability of decoding when the first j subsets have false keys and the remaining subsets encode the correct key. If $| p_{j-1} - p_j | > p/m$ then it must be that S_j contains a traitor. We note that at least one such j always exists.

To efficiently find a subset that contains a traitor, employ the binary-search-like method described hereby that efficiently finds a pair of values p_j and p_{j-1} among $p_0, ..., p_m$ satisfying $| p_{j-1} - p_j | > p/m$. Starting with the entire interval [0,m], the search is repeatedly narrowed down to an arbitrary interval [a,b]. At each stage, the middle value $p_{a+b/2}$ is computed and the interval is further halved either to the left half or to the right half, depending on difference between $p_{a+b/2}$ and the endpoint values p_a and p_b of the interval. Observe that p_0 is p and p_1 is 0. Furthermore, in most practical cases, p is 1; in other words, the clone always decrypts during normal operation. The method is outlined below; it outputs the index j.

SubsetTracing(a,b,p_a,p_b)

```
If (a=b-1)
    return b
Else
    Let c = ⌈a+b/2⌉
    Compute p_c
    If | p_c - p_a | ≥ | (p_a - p_b)/2 |
            SubsetTracing(a,c,p_a,p_c)
    Else
            SubsetTracing(c,b,p_c,p_b)
```

Efficiency: Subset tracing requires *O(log m)* evaluations of p_i. An evaluation of p_j must be within an accuracy that reveals a difference of the order of *1/m*; namely, p_j needs to be estimated so the difference between its true value and its estimated value does not exceed *1/2m* with assurance probability of 1-ε. Also , the true value of p_j can be as small as of the order of *1/m*. It follows from Chernoff bounds that $m^2 log$ (1/ε) ciphertext queries to the decoding box are sufficient to estimate such p_j within the required accuracy. Hence, a subset tracing procedure that works with success probability of ε log m requires $m^2 log m \; log$ (1/ε) ciphertext queries over the entire procedure.

Subset Tracing with Noisy Binary Search: It is possible to improve the efficiency of the subset tracing procedure by viewing it as a noisy-binary search procedure. The noisy binary search assumes that at each step of the decision tree the correct decision is obtained with probability 1-Q, where Q is a value close to 1/2, for example Q=1/3. In a model where each answer is correct with some fixed probability (say greater than 2/3) that is independent of history it is possible to perform binary search in *log N + log 1/Q* queries where *log N* is the number levels in the search tree. Specifically for our case, can we assume that the computation of p_c at each step may yield a faulty value with probability Q. this yields that the number of the queries required over the entire procedure can be reduced to $m^2 (log\ m + log\ 1/Q)$.

Improving The Tracing Algorithm

Among the *t log N* subsets generated by the basic tracing algorithm, only *t* actually contain a traitor. The idea is to repeatedly merge those subsets which are not known to contain a traitor so as to reduce the number of subsets in the partition . For some encryption schemes it is possible to efficiently perform this merging, thus reducing the length of the message required to trace *t* traitors. For example, the preferred embodiment uses the Subset Difference method as the encryption scheme and requires a message of

only *5t* to trace *t* traitors (instead of *t logN*).

Specifically, we maintain at each iteration a **frontier** of at most 2t subsets and merge the rest of the subsets. In the following iteration a subset that contains a traitor is further partitioned; as a result, a new frontier is defined and the remaining subsets are re-grouped.

Frontier subsets

Let $S = S\_i_1, S\_i_2, \ldots, S\_i_m$ be the partition at the current iteration. A pair of subsets S_i_{j1} and S_i_{j2} is said to be in the frontier if S_i_{j1} and S_i_{j2} resulted from a split-up of a single subset at an earlier iteration. Also neither S_i_{j1} nor S_i_{j2} was singled out by the subset tracing procedure so far. This definition implies that the frontier is composed of at most t disjoint pairs of **buddy subsets**.

The improved tracing algorithm proceeds in iterations. Every iteration starts with a partition $S = S\_i_1, S\_i_2, \ldots, S\_i_m$. Denote by $F \subseteq S$ the frontier of S. An iteration consists of the following steps, by the end of which a new partition S' and a new frontier F' is defined.

- As before, use the Subset Tracing procedure to find a subset S_i_j that contains a traitor. If the tracing procedure outputs that the box can not decrypt with S then we are done. Otherwise, split S_i_j into S^1 and S^2.
- Set $F' = F \cup S^1 \cup S^2$ (include S^1 and S^2 in the new frontier). Furthermore, if S_i_j was in the frontier F and S_i_k was its buddy-subset in F then $F' = F' \setminus S\_i_k$ (remove S_i_k from the new frontier).
- Compute a cover C for all receivers that are not covered by F'. Define the new partition S' as the union of C and F'.

An encryption method that can construct a small cover C for the non-frontier sets in the third step can take advantage of this improvement.

Tracing Traitors from Many Boxes

As new illegal decoding boxes, decoding clones and hacked keys are continuously being introduced during the lifetime of the system, a revocation strategy needs to be adopted in response. This revocation strategy is computed by first revoking the identities of all the receivers that need to be excluded, resulting in some partition S_0.

To trace traitors from possibly more than one illegal decoder and make all of these boxes non-decoding, the tracing algorithm needs to be run **in parallel** on all boxes by providing all boxes with the same input. The initial input is the partition S_0 that results from the set of all users that have not been revoked so far. As the algorithm proceeds, when the **first** box detects a traitor in one of the sets it re-partitions accordingly and the new partition is now input to **all** boxes simultaneously. The output of this simultaneous algorithm is a partition (or "revocation strategy") that renders all revoked receivers and illegal black boxes invalid.

3. If the same advantage or problem has been identified by others (inside/outside IBM), how have those others solved it and does your solution differ and why is it better?

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